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## ACTIVE AND PASSIVE REMOTE SENSING OF ICE

Under the sponsorship of the ONR contract N00014–89–J–1107, we have published 14 journal and conference papers and 3 student theses.

Strong permittivity fluctuation theory is used to solve the problem of scattering from a medium composed of completely randomly oriented scatterers under the low frequency limit. Based on Finkel'berg's approach [1964], Gaussian statistics is not assumed for the renormalized scattering sources. The effective permittivity is obtained under the low frequency limit and the result is shown to be isotropic due to no preferred direction in the orientation of the scatterers. Numerical results of the effective permittivity are illustrated for oblate and prolate spheroidal scatterers and compared with the results for spherical scatterers. The results derived are shown to be consistent with the discrete scatterer theory. The effective permittivity of random medium embedded with nonspherical scatterers shows a higher imaginary part than that of spherical scatterer case with equal correlation volume. Under the distorted Born approximation, the polarimetric covariance matrix for the backscattered electric field is calculated for the half-space randomly oriented scatterers. The nonspherical geometry of the scatterers shows significant effects on the cross-polarized backscattering returns $\sigma_{hv}$ and the correlation coefficient $\rho$ between $HH$ and $VV$ returns. The polarimetric backscattering scattering coefficients can provide useful information in distinguishing the geometry of scatterers.

A multivariate K-distribution, well supported by experimental data, is proposed to model the statistics of fully polarimetric radar clutter of earth terrain. In this approach, correlated polarizations of backscattered radar returns. are characterized by a covariance matrix and homogeneity of terrain scatterers is characterized by a parameter $\alpha$. As compared with C-, L- and P-band polarimetric SAR image data, simultaneous measured by Jet Propulsion Laboratory (JPL). $\alpha$ appears to decrease from C- to P- band for either forest, clear-cut, and desert areas.

The random medium model with three-layer configuration is developed to study fully polarimetric scattering of electromagnetic waves from geophysical media. This model can account for the effects on wave scattering due to weather, diurnal and seasonal variations, and atmospheric conditions such as ice under snow, meadow under fog, and forest under mist. The top scattering layer is modeled as an isotropic random medium which is characterized by a scalar permittivity. The middle scattering layer is modeled as an anisotropic random medium with a symmetric permittivity tensor whose optic axis can be tilted due to the preferred alignment of the embedded scatterers. The bottom layer is considered as a homogeneous half-space. Volume scattering effects of both random media are described by three-dimensional correlation functions with variances and correlation lengths corresponding to the strengths of the permittivity fluctuations and the physical sizes of the inhomogeneities, respectively. The strong fluctuation theory is used to derive the mean fields in the random media under the bilocal approximation with singularities of the dyadic Green's functions properly taken into account and effective permittivities of the random media are calculated with two-phase mixing formulas. The distorted Born approximation is then applied to obtain the covariance matrix which describes the fully polarimetric scattering properties of the remotely sensed media.

The three-layer configuration is first reduced to two-layers to observe fully polarimetric scattering directly from geophysical media such as snow, ice, and vegetation. Such media exhibit reciprocity as experimentally manifested in the close proximity of the measured backscattering radar cross sections $\sigma_{vh}$ and $\sigma_{hv}$ and theoretically established in the random medium model with symmetric permittivity tensors. The theory is used to investigate the signatures of isotropic and anisotropic random media on the complex correlation coefficient $\rho$ between $\sigma_{hh}$ and $\sigma_{vv}$ as a function of incident angle. For the isotropic random medium, $\rho$ has the value of approximately 1.0. For the untilted anisotropic random medium, $\rho$ has complex values with both the real and imaginary parts decreased as the incident angle is increased. The correlation coefficient $\rho$ is shown to contain information about the tilt of the optic axis in the anisotropic random medium. As the tilted angle becomes larger, the magnitude of $\rho$ is maximized at a larger incident angle where the phase of $\rho$ changes its sign. It should be noted that the tilt of the optic axis is also related to the nonzero depolarization terms in the covariance matrix which will also be considered.

The effects on polarimetric wave scattering due to the top layer are identified by comparing the three-layer results with those obtained from the two-layer configuration. The theory is used to investigate the effects on polarimetric radar returns due to a low-loss and a lossy dry-snow layers covering a sheet of thick first-year sea ice. For the low-loss snow cover, both $\sigma_{hh}$ and $\sigma_{vv}$ are enhanced compared to those observed from bare sea ice. Furthermore, the boundary effect is manifested in the form of the oscillation on $\sigma_{hh}$ and $\sigma_{vv}$. The oscillation can also be seen on the real and imaginary parts of the correlation coefficient $\rho$. The magnitude of $\rho$, however, does not exhibit the oscillation while clearly retaining the same characteristics as observed directly from the uncovered sea ice. In contrast to the low-loss case, the lossy top layer can diminish both $\sigma_{hh}$ and $\sigma_{vv}$ and depress the boundary-effect oscillation. When the thickness of the lossy top layer increases, the behavior of the correlation coefficient $\rho$ becomes more and more similar to the isotropic case signifying that the information from the lower anisotropic layer is masked. At appropriate frequency, the fully polarimetric volume scattering effects can reveal the information attributed to the lower layer even if it is covered under another scattering layer. Due to the physical base, the random medium model renders the polarimetric scattering information useful in the identification, classification, and radar image simulation of geophysical media.

Polarimetric calibration algorithms are developed to provide tools for polarimetric radar calibration. The transmission and receiving ports of the polarimetric radar are modelled by two unknown polarization transfer matrices. These two matrices are solved in terms of the measurements from three in-scene reflectors with different scattering matrices. All possible combinations of calibration targets are discussed and the solutions of each cases are presented. Thus if three scatterers with known scattering matrices, not necessarily man-made, are known to exist within a radar image, the whole image can be calibrated accordingly by using our exact solutions. The effects of misalignment and receiver noises will be illustrated for several sets of calibration targets.

Polarimetric terrain backscattering data observed with satellite and airborne synthetic aperture radars (SAR) have demonstrated potential applications in geologic mapping and terrain cover classification. In previous publications on this subject, Gaussian statistics have been frequently assumed for the radar return signal to build the Bayes terrain classifier. However, abundant experimental evidence shows that the terrain radar clutter is non-Gaussian, i.e., non-Rayleigh in amplitude distribution. Among many non-Gaussian statistics, the K-distribution has proven to be useful in characterizing the amplitude distribution of electromagnetic echoes from various objects, including diverse ground surfaces, sea surface and wave propagation through atmospheric turbulence.

A multivariate K-distribution is proposed to model the statistics of fully polarimetric data from earth terrain with polarizations HH, HV, VH, and VV. In this approach, correlated polarizations of radar signals, as characterized by a covariance matrix, are treated as the sum of $N$ n-dimensional random vectors; $N$ obeys the negative binomial distribution with a parameter $\alpha$ and mean $\overline{N}$. Subsequently, an n-dimensional K-distribution, with either zero or nonzero mean, is developed in the limit of infinite $\overline{N}$ or illuminated area. The probability density function (PDF) of the K-distributed vector normalized by its Euclidean norm is independent of the parameter $\alpha$ and is the same as that derived from a zero-mean Gaussian-distributed random vector. High-order normalized intensity moments and cumulative density functions (CDF) of experimental data obtained from MIT Lincoln Laboratory and the Jet Propulsion Laboratory are compared with theoretical values of the K-distribution. The above model is well supported by experimental data in the form of polarimetric measurements.

The three-layer random medium model is developed for microwave remote sensing of snow-covered sea ice. The electromagnetic wave theory and strong fluctuation theory are employed to study the propagation and volume scattering of electromagnetic waves in the medium. With the application of the Feynman diagrammatic technique and the renormalization method, mean fields for the isotropic and anisotropic random media are derived under the bilocal approximation. Then, the effective permittivities for both random media are obtained from the dispersion relations of the mean fields. Further, with the discrete-scatterer concept for two-phase mixtures, the scattering parts of effective permittivities are computed, in the low-frequency limit, for both isotropic and anisotropic random media with specified correlation functions. The distorted Born approximation is then used to compute the co-polarized and cross-polarized backscattering coefficients which are compared with scatterometer data at 9 and 13 GHz for bare and dry-snow covered thick first year (TFY) sea ice taken at Point Barrow, NWT.

A radar clutter model is used to simulate fully polarimetric returns for a stepped frequency radar. The purpose is to create synthetic site dependent clutter signatures that can be utilized in a hardware-in-the-loop test system. The fully polarimetric, multi-frequency, multi-incident angle random medium model is employed to generate normalized backscatter coefficients of terrain clutter. This model is used to generate the polarimetric terrain clutter covariance matrices for each of $N$ high resolution range bins, at each of the $M$ discrete frequencies. The random medium model allows us to include the effect of the terrain local incident angle on the clutter covariance matrix elements. In the simulation, we assume that there is a single clutter class within each of the $N$ range bins, although the depression angle may vary from bin to bin. The covariance matrices are decomposed and multiplied by complex Gaussian noise in order to generate the normalized electric fields in the backscattering direction for each of the $N$ range bins, at each of the $M$ discrete frequencies. These fields are then coherently added, taking into account the effects of both terrain elevation and range. This yields a single frequency polarimetric return that a radar would measure from the specified terrain. The radar return for each of the other discrete frequencies is calculated in a similar manner. The result is the clutter's low resolution range polarimetric profile, i.e., the backscattered signal response within the beam footprint of the radar antenna. Each discrete frequency is simulated and the effects of shadowing and overlay are taken into account. The simulation produces coherent phase-history clutter returns which can be coherently superimposed on the target phase-history returns. The combined (or clutter only) returns are processed to obtain either (1) the coherent, high resolution range profile or (2) the noncoherent, autocorrelation range profile.

Earth terrains are modeled by a two-layer configuration to investigate the polarimetric scattering properties of the remotely sensed media. The scattering layer is a random medium characterized by a three-dimensional correlation function with correlation lengths and variances respectively related to the scatter sizes and the permittivity fluctuation strengths. Based on the wave theory with Born approximations carried to the second order, this model is applied to derive the Mueller and the covariance matrices which fully describe the polarimetric scattering characteristics of the media. Physically, the first- and second-order Born approximations account for the single and double scattering processes.

For an isotropic scattering layer, the five depolarization elements of the covariance matrix are zero under the first-order Born approximation. For the uniaxial tilted permittivity case, the covariance matrix does not contain any zero elements. To account for the randomness in the azimuthal growth direction of leaves in vegetation, the backscattering coefficients are azimuthally averaged. In this case, the covariance matrix contains four zero elements although the tilt angle is not zero. Under the second-order Born approximation, the covariance matrix is derived for the isotropic and the uniaxial untilted random permittivity configurations. The results show that the covariance matrix has four zero elements and a depolarization factor is obtained even for the isotropic case.

To describe the effect of the random medium on electromagnetic waves, the strong permittivity fluctuation theory, which accounts for the losses due to both of the absorption and the scattering, is used to compute the effective permittivity of the medium. For a mixture of two components, the frequency, the correlation lengths, the fractional volume, and the permittivities of the two constituents are needed to obtain the polarimetric backscattering coefficients. Theoretical predictions are illustrated by comparing the results with experimental data for vegetation fields and sea ice.

The correlation function plays the important role in relating the electrical response of the geophysical medium to its physical properties. In the past, the volume scattering effect of electromagnetic waves from geophysical media such as vegetation canopies and snow-ice fields has been studied by using the random medium models. Even though theoretical treatments were rigorous within certain constraints, the correlation functions were chosen according to researchers' knowledge and experience on physical properties of scatterers. Correlation functions have been extracted from digitized photographs of cross-sectional samples for snow and lake ice and artificially grown saline ice. It was shown that the extracted correlation lengths corresponded to the physical sizes of ice grains, air bubbles, and brine inclusions. Also the functional forms of the extracted correlation functions were shown to be dependent on the shape and orientation of embedded inhomogeneities. To illustrate the importance of the correlation function study, the extracted correlation lengths for saline ice sample were then used to derive the effective permittivity and compared with in situ dielectric measurements of the sample. However, without any mathematical model, it is very difficult to relate the distribution, size, shape, and orientation of the scatterers to the variances, correlation lengths, and functional dependence of the correlation function.

The first analytical survey of correlation functions for randomly distributed inhomogeneities with arbitrary shape can be traced back to the work by Debye and his co-workers. In order to explain the fourth-power law of the intensity distribution of X-rays scattered by porous materials (hole structures) at larger angles, Debye *et al.* derived the correlation function for two-phase isotropic random medium. They have shown that materials with holes of perfectly random shape, size, and distribution can be characterized by a spherically symmetric correlation function of exponential form. The correlation length was related to the fractional volume and the specific surface which are among the important factors in determining the catalytic activity.

To demonstrate the feasibility of the method, we first derive in detail the correlation function and the correlation length for isotropic random medium with spherical inclusions. Then, the correlation function study is extended to consider randomly distributed prolate spheroids with preferred alignment in the vertical direction for the anisotropic random medium. A scaling scheme is employed to transform the surface equation of prolate spheroids to that of spheres so that the same approach in the isotropic case can be utilized to derive the correlation function. Since most of geophysical media are complex materials such as wet snow which is a mixture of air, ice grains, and water content and multi-year sea ice which consists of pure ice, air bubbles, and brine inclusions, the correlation function study for three-phase mixtures is also established. Two different kinds of inclusions with spherical and spheroidal shapes are considered. It is found that there is a close relationship between the form of the correlation function and the distribution, geometrical shape, and orientation of the scatterers. Also, the calculated correlation lengths are related to the fractional volumes and total common surface areas. These results can be utilized to identify the feature signature and characteristics through its microscopic structure. For instance, dry or slush snow can be distinguished from grain sizes, water contents, and density via the comparison of the variances and correlation lengths. The form of the correlation function provides the information about the physical shape and alignment of brine inclusions in addition to the concentration of brine inclusions versus air bubbles for the tracing of the sea-ice signatures such as thick first-year sea ice and multi-year sea ice.

There has been considerable interest in the use of additional information provided by the polarization in the remote sensing of earth terrain. By measuring the amplitudes and phases of the $HH$, $HV$, and $VV$ returns in the backscattered direction, fully polarimetric scattering characteristics of the earth terrain can be obtained. Once the scattering matrix is known, then the scattered power for any receiving and transmitting polarizations can be synthesized. The variation of the synthetic aperture radar (SAR) images due to the changes in the polarization has motivated the study in terrain discrimination and classification using the fully polarimetric SAR images. The problem of determining the optimal polarizations that maximizes contrast between two scattering classes is first presented. Then the more general problem of classifying the SAR images into multiple classes using the polarimetric information is presented.

The problem of determining the optimal polarization that maximizes the contrast between two terrain classes in the polarimetric radar images has many practical application in terrain discrimination. A systematic approach is presented for obtaining the optimal polarimetric matched filter, i.e., that filter which produces maximum contrast between two scattering classes. The maximization procedure involves solving an eigenvalue problem where the eigenvector corresponding to the maximum contrast ratio is optimal polarimetric matched filter. To exhibit the physical significance of this filter, it is transformed into its associated transmitting and receiving polarization states, written in terms of horizontal and vertical vector components. For the special case where the transmitting polarization is fixed, the receiving polarization which maximizes the contrast ratio is also obtained. Polarimetric filtering is then applied to synthetic aperture radar (SAR) images obtained from the Jet Propulsion Laboratory. It is shown, both numerically and through the use of radar imagery, that maximum image contrast can be realized when data is processed with the optimal polarimetric matched filter.

Supervised and unsupervised classification procedures are also developed and applied to synthetic aperture radar polarimetric images in order to identify their various earth terrain components for more than two classes. For supervised classification processing, the Bayes technique is used to classify fully polarimetric and normalized polarimetric SAR data. Simpler polarimetric discriminates, such as the absolute and normalized magnitude response of the individual receiver channel returns, in addition to the phase difference between the receiver channels, are also considered. Another processing algorithm, based on comparing general properties of the Stokes parameters of the scattered wave to that of simple scattering models, is also discussed. This algorithm, which is an unsupervised technique, classifies terrain elements based on the relationship between the orientation angle and handedness of the transmitting and receiving polarization states. These classification procedures have been applied to San Francisco Bay and Traverse City SAR images, supplied by the Jet Propulsion Laboratory. It is shown that supervised classification yields the best overall performance when accurate classifier training data is used, whereas unsupervised classification is applicable when training data is not available.

Supervised and unsupervised classification procedures are developed and applied to synthetic aperture radar (SAR) polarimetric images in order to identify its various earth terrain components. For the supervised classification processing, the Bayes technique is utilized to classify fully polarimetric and normalized polarimetric SAR data. Simpler polarimetric discriminates, such as the unnormalized and normalized magnitude response of the individual receiver channel returns in addition to the phase difference between the receiver channels are also considered. Covariance matrices are computed for each terrain class from selected portions within the image where ground truth is available, under the assumption that the polarimetric data has a multivariate Gaussian distribution. These matrices are used to train the optimal classifier, which in turn is used to classify the entire image. In this case, classification is based on determining the *distances* between the training classes and the observed feature vector, then assigning the feature vector to belong to that training class for which the distance was minimum. Another processing algorithm based on comparing general properties of the Stokes parameters of the scattered wave to that of simple scattering models is also discussed. This algorithm, which is an unsupervised technique, classifies terrain elements based on the relationship between the orientation angle and handedness, or ellipticity, of the transmitted and received polarization state. These classification procedures will be applied to San Francisco Bay and Traverse City SAR imagery, supplied by the Jet Propulsion Laboratory. It is shown that fully polarimetric classification yields the best overall performance. Also, in some selected areas where the observed amplitudes of the returns are quite different than that of the training data, classification techniques not based on the absolute amplitudes of the returns, e.g., the normalized polarimetric classifier, produced a more consistent result with respect to the ground truth data.

The normalized polarimetric classifier is proposed such that only the relative magnitudes and phases of the polarimetric data will be utilized to discriminate terrain elements. For polarimetric data with arbitrary probability density function (PDF), the distance measures of the normalized polarimetric classifier based on a general class of normalization functions are shown to be equivalent to one another. The normalized polarimetric classifier thus derived will be optimal among all normalization schemes, when the system absolute calibration factors are common to all polarimetric channels. Further assuming a multivariate complex Gaussian distribution for the un-normalized data, the distance measure of the normalized polarimetric classifier is given explicitly and turns out to be also independent of the number of scatterers. The usefulness of the normalized polarimetric classifier is demonstrated by the classification of trees and grass in the experimental data obtained from Lincoln Laboratory. The classification error is shown to be the smallest among those of magnitude ratio or phase difference classifications.

## PUBLICATIONS SPONSORED BY THE ONR CONTRACT:

Scattering from Randomly Oriented Scatterers with Strong Permittivity Fluctuations, (H. A. Yueh, R. T. Shin, and J. A. Kong), accepted for publication in *Journal of Electromagnetic Waves and Applications.*

K-distribution and Multi-frequency Polarimetric Terrain Radar Clutter, (H. A. Yueh, J. A. Kong, R. T. Shin, H. A. Zebker, and T. Le Toan), accepted for publication in *Journal of Electromagnetic Waves and Applications.*

Three-Layer Random Medium Model for Fully Polarimetric Remote Sensing of Geophysical Media, (S. V. Nghiem, F. C. Lin, J. A. Kong, R. T. Shin, and H. A. Yueh), *Progress in Electromagnetics Research Symposium,* Boston, Massachusetts, July 25–26, 1989.

Calibration of Polarimetric Radars Using In-Scene Reflectors, (H. A. Yueh, J. A. Kong, R. M. Barnes and R. T. Shin), *Progress in Electromagnetics Research Symposium,* Boston, Massachusetts, July 25–26, 1989.

K-distribution and Polarimetric Terrain Radar Clutter, (H. A. Yueh, J. A. Kong, J. K. Jao, R. T. Shin, and L. M. Novak), *Progress in Electromagnetics Research Symposium,* Boston, Massachusetts, July 25–26, 1989.

Application of Three-Layer Random Medium Model for Microwave Remote Sensing of Snow-covered Sea Ice (F. C. Lin, J. A. Kong, and R. T. Shin), submitted for publication in *Journal of Geophysical Research.*

Polarimetric Remote Sensing of Earth Terrain with Two-Layer Random Medium Model, (M. Borgeaud, J.A. Kong, R.T. Shin, and S. V. Nghiem), *Progress in Electromagnetics Research Symposium,* Boston, Massachusetts, July 25–26, 1989.

Correlation Function Study for Random Media with Multiphase Mixtures, (F. C. Lin, H. A. Yueh, J. A. Kong and R. T. Shin), *Progress in Electromagnetics Research Symposium,* Boston, Massachusetts, July 25–26, 1989.

Contrast and Classification Studies of Polarimetric SAR Images for Remote Sensing of Earth Terrain (H. H. Lim, H. A. Yueh, J. A. Kong, R. T. Shin, and J. J. van Zyl), *Progress in Electromagnetics Research Symposium,* Boston, Massachusetts, July 25-26, 1989.

Application of Three-Layer Random Medium Model to Polarimetric Remote Sensing of Snow and Sea Ice, (S. V. Nghiem, J. A. Kong, R. T. Shin, and H. A. Yueh) *North American Sea Ice Work Shop*, Amherst, Massachusetts, June 26–28, 1989.

Theoretical Prediction of EM Bias, (David V. Arnold, Jin Au Kong, W. Kendall Melville, and Robert W. Stewart), *Progress in Electromagnetics Research Symposium,* Boston, Massachusetts, July 25–26, 1989.

The Measurement and Modelling of Sea-state Bias in SAXON (W. K. Melville, J. A. Kong, R. H. Stewart, W. C. Keller, A. Jessup, D. Arnold, A. Slinn), *IGARSS '89 and 12th Canadian Symposium on Remote Sensing,* Vancouver, Canada, July 10-14, 1989.

A Neural Net Method for High Range Resolution Target Classification (R. G. Atkins, R. T. Shin, and J. A. Kong), accepted for publication in *Journal of Electromagnetic Waves and Applications.*

Classification of Earth Terrain using Synthetic Aperture Radar Images (H. Lim, A. A. Swartz, H. A. Yueh, J. A. Kong, R. T. Shin, and J. J. Van Zyl), *Journal of Geophysical Research,* Vol. 94, No. B6, 7049–7057, June 10, 1989.